FRAUNHOFER INSTITUTE FOR WIND ENERGY AND ENERGY SYSTEM TECHNOLOGY

THE IMPORTANCE OF OFFSHORE WIND ENERGY IN THE ENERGY SECTOR AND FOR THE GERMAN ENERGIEWENDE

Summary

COMMISSIONED BY THE

STIFTUNG OFFSHORE WINDENERGIE

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Executive Summary

Offshore wind energy is absolutely essential to achieve the energy transition in Germany. The present study shows that offshore wind will ensure security of supply, system quality, and affordable overall costs in the future energy system, thanks to its excellent power plant characteristics. Wind turbines at sea can provide electricity almost every single hour of the year with about as many operating hours as conventional power plants; they produce power about 340 days per year, and that power production can be forecast fairly accurately. The turbines are also much better equipped to provide operating reserve than other fluctuating renewable energy sources and therefore play a key role in stabilizing the power system.

The present study analyzed the feasibility, functionality, and system costs for energy supply in the year 2050 based on three scenarios. Renewable energy provides 80 percent of final energy demand in all three scenarios but in different proportions. Potential limits are defined for onshore wind, offshore wind, and photovoltaics that constitute sensible expansion in terms of both economic and societal aspects.

Exporting power to the grid from fluctuating renewable energy sources requires greater flexibility in the form of back-up and storage capacity as well as curtailment. In the scenario with the highest share of offshore wind energy (optimized growth scenario), this factor is much less of a concern. Flexibility costs are, in turn, 2.9 to 5.6 billion euros per year lower than in the comparison scenarios with a high share of onshore wind energy (onshore growth scenario) or photovoltaics (photovoltaics growth scenario). There are also positive effects on overall costs – all power production costs and flexibility costs combined – with savings of 0.9 to 6.1 billion euros per year compared to the other scenarios. Further potential for significant cost reductions would come from a joint European North Sea offshore grid.

A renewable energy mix with a large share of offshore wind energy is therefore more cost-effective in the long term than a generation mix without this technology. Levelised costs of electricity – that is, all costs for a kilowatt-hour (kWh) of produced power – for wind and solar power continue to come closer by 2050. Therefore technologies that can stabilize and balance power supply are key to the overall efficiency of the energy system. Offshore wind energy could play a leading role.

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Overview of the study findings

Energy at a turning point: the mix in 2050
By 2050, Europe plans to reduce its greenhouse gases by 80 to 95 percent compared to 1990 levels; the German government confirmed its dedication to this goal in its energy concept of 2010. Such a large decrease can only be achieved with a complete transformation of the energy system which has renewable energy at its center.

The present study focuses on the target year of 2050 with the following assumptions: renewable energy will provide 80 percent of final energy demand, while German energy consumption will be nearly 40 percent lower than it is today. Electricity will play a more important role as a result of new uses in heating and transportation sector (power-to-heat, power-to-gas, electromobility, etc.). At over 900 TWh, power production will be more than 50 percent above current levels. In order to produce that amount almost completely without CO_2 emissions, a broad mix of renewable energy sources is essential.

Three scenarios in three steps
In a three-step process, possible combinations of fluctuating renewable energy sources were analyzed in order to determine sustainable scenarios for the energy mix in 2050. The **first step** focused on the most balanced way to provide power. The key indicator was residual load, the amount of power still needed each hour of the year after all fluctuating renewable power has been considered. The stipulation that the fluctuations in the residual load must be as small as possible led to an “optimal mix” for the future energy supply based on these technologies.

In the **second step**, the potential limits for wind and solar power were determined. They are defined in this study as the highest amounts of power realistically possible based on economic and societal criteria. It was found that 390 TWh per year could be produced if two percent of Germany’s land area was used for onshore wind energy. Provided all of the generally suitable areas in the North and Baltic Seas were used, offshore wind energy could contribute 258 TWh. For photovoltaics, all available roof surfaces and a portion of ground surface would produce 248 TWh per year.

In the **third step**, both calculations – the “optimal mix” and the three technologies’ potential limits – were combined. The most ideal match was found in the study’s optimized growth scenario, in which the previously defined potential for onshore and offshore wind energy is completely utilized (390 TWh and 258 TWh, respectively), while photovoltaics contributes significantly with 152 TWh.

Two comparison scenarios were also studied, which assume that only the offshore turbines currently in operation and/or being built will provide power (3 gigawatts (GW) of capacity and 14 TWh). To make up the difference, they assume a much higher contribution from onshore wind energy (635 TWh; onshore growth scenario) or significant photovoltaics expansion (396 TWh; photovoltaics growth scenario).

Power from biomass and hydropower is a fixed value in all three scenarios (64 TWh) and, along with load management, is only taken into consideration in the flexibility cost assessment.

Higher system quality and lower system costs with offshore wind
As generation cost for the various renewable energy sources equalize in the coming decades, the values of individual technologies will increasingly distinguish themselves

based on their contribution to the energy system's overall efficiency. In order to evaluate this factor, the residual load after load management for each hour in one year was studied for the three scenarios. The analysis of the resulting flexibility costs included the following parameters:

- investments in **storage**
- investments in **back-up capacity**
- **fuel costs** for the residual power demand
- **curtailment** of excess production.

Findings: Offshore wind energy significantly decreases system costs. In all four aspects, the optimized growth scenario is more cost-effective than the comparison scenarios, with a drop in flexibility costs of as much as 5.6 billion euros per year.

The cost benefits of offshore wind still prevail when the cumulative power production costs for each scenario are added to the flexibility costs; in that case, the net effect of offshore wind on total costs is 0.9 to 6.1 billion euros per year. **Offshore wind energy therefore consistently lowers overall power system costs.**

Further significant cost savings can be achieved by the European collaboration on a North Sea offshore grid for Belgium, Denmark, Germany, the UK, Norway, and the Netherlands. Making use of cross-border balancing capacity and increased electricity trade decreases the total residual load for all of the North Sea countries by 16 percent.

Overview of the annual flexibility costs and levelised costs of electricity per year in the three scenarios for the year 2050

	Optimized growth scenario	Onshore growth scenario	Photovoltaics growth scenario
Back-up capacity (GW)	54,4	62,0	62,6
Investment costs – annuity basis (billions of euros)	1,8	2,0	2,0
Residual power demand (TWh)	53,4	68,9	81,8
Fuel costs for residual power demand (billions of euros)	4,8	6,2	7,4
Storage capacity (GW)	67,9	74,3	83,9
Investment costs – annuity basis (billions of euros)	3,2	3,6	4,0
Excess production (TWh)	20,3	35,9	51,2
Curtailment costs (billions of euros)	1,3	2,3	3,4
Cumulative flexibility costs (billions of euros)	**11,1**	**14,0 (+26%)**	**16,8 (+50%)**
Cumulative levelised costs of electricity (billions of euros)	**52,4**	**50,4**	**52,9**
Total costs for flexibility and power production (billions of euros)	**63,5**	**64,5**	**69,7**

Figures are rounded; totals were calculated with non-rounded figures.

Offshore has excellent power plant characteristics

The positive effects in the optimized growth scenario are largely due to offshore wind farms' excellent power production characteristics, especially predictability and the ability to provide operating reserve.

Predictability: Offshore wind turbines already have very high full-load hours and will achieve over 4,800 in the future. That leads to much more than 8,000 operating hours per year, or electricity production on around 340 days per year. Production fluctuations are also fairly small; in 70 percent of all annual hours, production varies by no more than 10 percent of installed capacity from one hour to the next. Production can therefore be forecast with high accuracy, and there is less need for operating reserve and balancing power plants (storage, etc.).

An offshore wind farm's power yield can be more accurately predicted than that of an onshore wind farm, with forecast errors less likely and deviations much smaller.

Operating reserve: In order for the power grid to remain stable, power consumption and power fed into the grid must be completely balanced at all times. Short-term gaps as the result of, for example, forecast errors, must be covered with operating reserves, and the plants providing that power must be extremely reliable. The research project 'Combined Renewable Power Plant' (Kombikraftwerk 2) conducted by multiple partners from industry and research proved that wind farms can provide positive and negative operating reserve capacity (primary, secondary, and tertiary). Thanks to their excellent predictability, offshore wind farms are much better suited to this task and can offer ten times as much operating reserve capacity than comparable farms onshore. Under present market regulations, the costs for providing this service with offshore wind farms amount to just one fourth of what they would be for onshore farms.

Outlook: offshore wind growth should be steadily expanded

In the energy system of tomorrow, offshore wind energy will make a major contribution to system security – at lower costs than other technologies in the mid and long term. In order to take advantage of this potential, its generation capacity in Germrany must be continuously expanded in the coming decades. The optimized growth scenario in this study assumes an offshore capacity of 54 GW by 2050, a figure that can only be reached if all areas of the German North and Baltic Seas currently considered suitable are, in fact, used.